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## EUROPEAN PATENT APPLICATION

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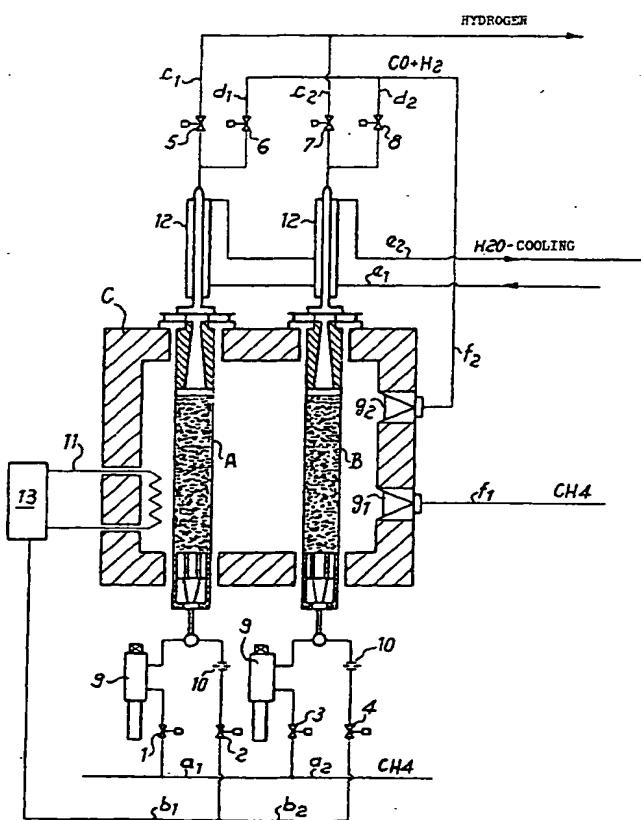
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### (54) Process and apparatus for the production of hydrogen from a gaseous hydrocarbon

(57) Procedure and system for the production of hydrogen from methane or other gaseous hydrocarbon, in which the methane is decomposed at high temperature in the presence of a catalyst supplying hydrogen and

carbon. The carbon which would pollute the catalyst is eliminated by means of a catalyst regeneration phase with steam, which generates a reaction gas that can be re-used as a source of energy (Fig. 1).



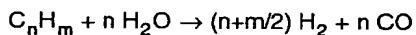
**Description**

[0001] This invention concerns a procedure and a system for the production of hydrogen by means of catalytic decomposition of methane or other gaseous hydrocarbon.

[0002] In particular the invention concerns a procedure and a system for the production of hydrogen by means of catalytic decomposition of methane and subsequent regeneration of the catalyst in one or more retorts. The catalyst used is porous, impregnated with nickel at 7%.

[0003] Hydrogen is used in large quantities to produce energy and heat and is the only fuel which, during combustion, produces non-polluting substances. Furthermore, it is used in the synthesis of organic compounds.

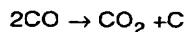
[0004] The best-known and most widely used chemical procedure for the industrial production of hydrogen is reforming of natural gaseous hydrocarbons (for example methane) or liquefied oil gases with steam, according to the following reaction.



[0005] For methane the above equation becomes:



[0006] The reaction gas (CO + 3H<sub>2</sub>) requires separation of the CO from the hydrogen, which is performed by reducing the temperature (preferably in a retort at a temperature between 300 °C and 600 °C), according to the following reaction:



[0007] The carbon dioxide is then eliminated via molecular sieves or by means of other difficult, uncertain and costly techniques.

[0008] The carbon produced is deposited in the form of soot on the bottom of the retort and must be continuously eliminated by means of an auger or by periodically cleaning the retort.

[0009] The aim of the present invention, therefore, is to provide a procedure and a system for the production of hydrogen from methane which permits economic problem-free production as regards separation of the CO and hydrogen gases and also, possibly, without interruptions due to cleaning of the retort.

[0010] According to the present invention, this aim has been achieved by catalytic decomposition (cracking) of the methane and regeneration of the catalyst using one or more retorts, with re-use of the reaction gases produced by regeneration of the catalyst.

[0011] The procedure for the production of hydrogen

according to the present invention comprises catalytic decomposition of natural gaseous hydrocarbons or liquefied oil gases at high temperature, according to the following reaction:

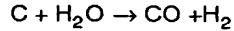
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(for methane CH<sub>4</sub> → C + 2H<sub>2</sub>)

10 and regeneration of the catalyst with steam or water preferably at the same cracking temperature (and in a CO<sub>2</sub> stream), involving elimination of the carbon deposited on the catalyst according to the equation:

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(in a CO<sub>2</sub> stream CO<sub>2</sub> + C → 2 CO).

20 [0012] The catalyst regeneration phase may be also obtained with a N<sub>2</sub>/CO<sub>2</sub> stream saturated with water (or steam).

[0013] Advantageously cracking of the methane occurs at a temperature between 1000°C and 1100°C, in a retort filled with a nickel based catalyst carried on a ceramic material support.

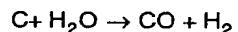
25 [0014] The hydrogen generated during cracking can be cooled and stored or used in fuel cells.

[0015] The carbon, in the form of very fine powder, is deposited on the ceramic support for the catalyst, gradually covering the ceramic support and thus reducing its effectiveness.

[0016] The activity of the catalyst is controlled during the procedure by detection and measurement of the non-cracked hydrocarbon at the retort outlet. When a

30 maximum pre-set amount of hydrocarbon is recorded at the retort outlet, the retort switches to the regeneration phase.

[0017] In the catalyst regeneration phase, steam is introduced into the retort which reacts with the carbon deposited according to the following reaction:



45 [0018] This reaction continues until all the carbon deposited on the support of catalyst during cracking is transformed into CO, or until the analyser detects the presence of CO in the gases emitted by the retort.

[0019] Subsequently the retort containing the regenerated catalyst returns to the hydrogen production phase.

[0020] The reaction gas (CO + H<sub>2</sub>) of the catalyst regeneration phase is re-used without separation of the components as fuel, for example for heating the generator itself. In the procedure according to the present invention, preferably two retorts are used, kept at the reaction temperature in one single hot chamber provided with self-recovery burners powered by methane.

[0021] Each of the two retorts is provided with a flow meter for measuring the methane flow and a flow rate regulator for the steam.

[0022] The retorts operate alternatively generating hydrogen and regenerating the catalyst, thus permitting a continuous production of hydrogen. According to the operating mode of each retort, the valve supplying the methane (for the retort generating hydrogen) or the steam (for the retort regenerating the catalyst) is opened.

[0023] A heat exchanger is provided in the hot chamber used for generation of the steam necessary in the catalyst regeneration phase. This heat exchanger can be a coil, for example. In this way, the heat generated is used to heat the retorts in the hot chamber, thus obtaining additional energy saving.

[0024] The two ends of the retorts are thermally insulated by means of a plug. A system diagram according to the present invention is shown in the only figure attached, provided purely as a non-restrictive example.

[0025] In the figure, A and B indicate two retorts filled with ceramic material which supports a catalyst at 7% nickel (but a catalyst at 4% - 5% nickel - minimum - has also been tested).

[0026] C indicates the hot chamber which encloses the two retorts A and B. The chamber is heated by combustible gas which enters via the supply elements  $f_1$  and  $f_2$ , provided with burners  $g_1$  and  $g_2$ .

[0027] The retorts A and B are supplied with a flow of a gaseous hydrocarbon (for example methane) via the pipe (supply element)  $a_1$  or  $a_2$ , or with a flow of steam via pipe  $b_1$  or  $b_2$ , according to their operating mode (generation of hydrogen or regeneration of the catalyst).

[0028] The flow of gaseous hydrocarbon (for example methane) entering the retort during the cracking phase is measured with a flow meter 9, while the quantity of steam entering for regeneration of the catalyst is regulated by means of a flow rate regulator 10.

[0029] Valve 1 or 3 connects the retort (A or B) to the flow of methane for the generation phase, while valve 2 or 4 connects the retort (A or B) to the steam flow for the catalyst regeneration phase.

[0030] The hydrocarbon and the steam enter the retort via a diffuser provided with holes.

[0031] The valve 5 or 7 controls outlet of the hydrogen generated via the pipe  $c_1$  or  $c_2$ . The valve 6 or 8 controls outlet of the gas ( $CO + H_2$ ), from the catalyst regeneration phase, via the pipe  $d_1$  or  $d_2$  for re-use, preferably in the procedure according to the present invention, as a source of energy.

[0032] 12 indicates a heat exchanger for cooling the gases produced in the procedure according to the present invention. The cooling water that circulates in the heat exchanger 12 enters via the supply pipes  $e_1$  and exits from the heat exchanger via the conveying pipes  $e_2$ .

[0033] In an alternative preferred embodiment of the system according to the present invention, said system

is also provided with a heat exchanger 11 connected to the steam generator 13 used for regenerating the catalyst.

[0034] For illustrative purposes, some results obtained according to a pilot embodiment of the present invention are given below, with one single retort operating alternatively in the production and regeneration phase.

[0035] The production of hydrogen obtainable by using one single retort is  $10\text{ m}^3/\text{h}$  with a methane supply of  $5\text{ m}^3/\text{h}$ . Cracking temperature was maintained around  $1000^\circ\text{C}$  to increase process yield.

[0036] Hydrogen is produced for one hour; the system then switches to the regeneration phase which can be considered terminated when the CO analyser shows a value of below 1%.

[0037] Surprisingly, nickel based catalyst supported on a ceramic material didn't quickly degrade at a cracking temperature set above  $1000^\circ\text{C}$ . This means that a high yield of the process and a long life of the catalyst may be attained at the same time.

[0038] Therefore, even if any suitable catalyst may be used - for instance cubes of refractory material soaked in nickel - a nickel based catalyst carried on a ceramic support is preferred since it is easy - and consequently cheap - to obtain.

[0039] Nickel based catalyst supported on other inorganic materials was also successfully tested.

[0040] By using two retorts it is possible to produce hydrogen from gaseous hydrocarbon - such as methane - without interruption; while one is producing hydrogen, the other is - at least for a certain amount of time - in regeneration mode.

[0041] The present invention, furthermore, permits energy saving by reusing the gas ( $CO + H_2$ ) from the catalyst regeneration phase as fuel for maintaining the temperature in the hot chamber.

[0042] As the skilled person can appreciate, hydrogen produced in the catalyst regeneration phase is not further separated from  $CO$ , since the high temperature cracking phase results in a high yield of the process (i.e. a great amount of hydrogen is produced at a cracking temperature greater or equal to  $1000^\circ\text{C}$ ).

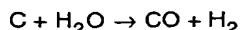
## Claims

1. Procedure for the production of hydrogen from a gaseous hydrocarbon, characterised in that it comprises a hydrogen generation phase in which the hydrocarbon is decomposed in the presence of a catalyst at high temperature, according to the following reaction:



and a catalyst regeneration phase with steam or

water with elimination of the carbon deposited on the catalyst, according to the reaction:



in which the reaction gas ( $\text{CO} + \text{H}_2$ ) from the catalyst regeneration phase is re-used as a source of energy.

2. Procedure according to claim 1, **characterised in that** the reaction gas from the catalyst regeneration phase is re-used as a source of energy in the process itself.
3. Procedure according to claim 1 or 2, **characterised in that** the two phases are performed, at least for a certain amount of time, parallel, in at least two retorts which operate alternatively generating hydrogen and regenerating the catalyst.
4. Procedure according to claim 1, 2 or 3, **characterised in that** the temperature of the cracking phase is between 1000 °C and 1100 °C.
5. Procedure according to claim 1, 2 or 3, **characterised in that** the retort(s) are filled or coated with catalyst supported on a ceramic material.
6. Procedure according to claim 5, **characterised in that** the catalyst is nickel-based.
7. Procedure according to claim 6, in which the catalyst contains nickel at 4% or more.
8. Procedure according to claim 1, 2 or 3, **characterised in that** the hydrogen obtained is cooled and stored or used in fuel cells.
9. Procedure according to claim 2, **characterised in that** the reaction gas from the regeneration phase is used for generating steam and/or for heating the retort(s).

10. System for the production of hydrogen from a gaseous hydrocarbon according to the procedure of claim 1 or 2, **characterised in that** it comprises:

- a retort (A or B)
- a hot chamber (C) enclosing the retort;
- means for supplying the hydrocarbon ( $a_1, a_2$ ) to the retort;
- means for supplying the steam ( $b_1, b_2$ ) to the retort;
- means for supplying combustible gas ( $f_1$ ) to a burner ( $g_1$ ) of the hot chamber;
- means for supplying the regeneration gas to an external heat generator and/or to a steam gen-

erator and/or to a burner ( $g_2$ ) in the hot chamber.

11. System for the production of hydrogen from a gaseous hydrocarbon according to the procedure of claim 3, **characterised in that** it comprises:

- two retorts (A and B);
- a hot chamber (C) enclosing the retorts;
- means for supplying hydrocarbon ( $a_1, a_2$ ) alternatively to the retorts;
- means for supplying steam alternatively ( $b_1, b_2$ ) to the retorts;
- means for supplying combustible gas ( $f_1$ ) to a burner ( $g_1$ ) of the hot chamber;
- means for supplying the regeneration gas to an external heat generator and/or to a steam generator and/or to a burner ( $g_2$ ) in the hot chamber.

12. System, according to claim 10 or 11, **characterised in that** the retort(s) use a catalyst supported on a ceramic material.

13. System according to claim 10 or 11, **characterised in that** the hot chamber (C) is provided with a heat exchanger (11) connected to a steam generator (13).

14. System according to claim 10 or 11, **characterised in that** it comprises, at the outlet of the retort(s), a heat exchanger (12) for cooling the gases produced.

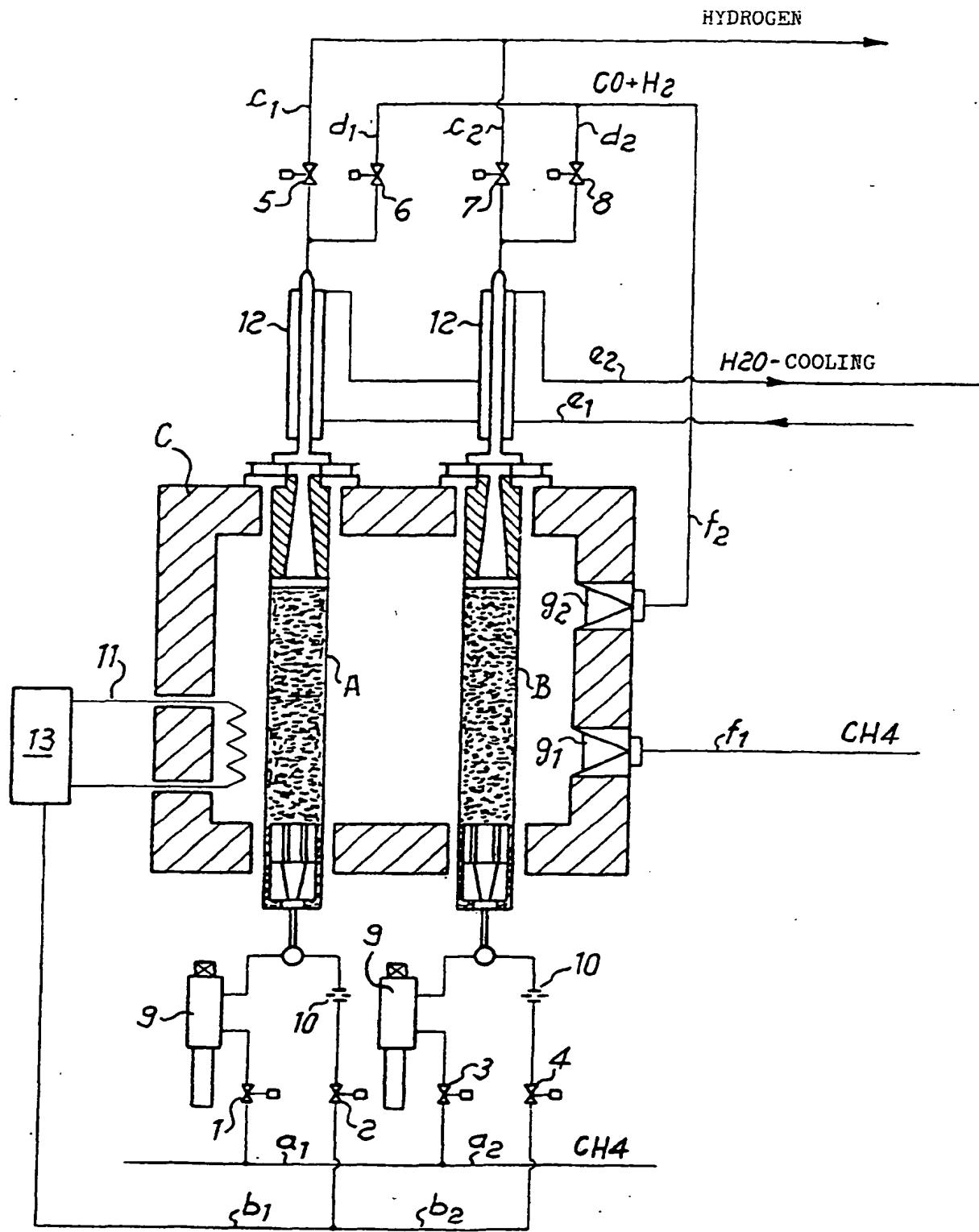
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## EUROPEAN SEARCH REPORT

Application Number  
EP 02 00 0169

DOCUMENTS CONSIDERED TO BE RELEVANT												
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)									
Y	R. AIELLO ET AL.: "Hydrogen production via the direct cracking of methane over Ni/SiO <sub>2</sub> : catalyst deactivation and regeneration" APPLIED CATALYSIS A: GENERAL., vol. 192, 2000, pages 227-234, XP001023644 ELSEVIER SCIENCE, AMSTERDAM., NL ISSN: 0926-860X * the whole document *	1-13	C01B3/26 B01J8/06									
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<p>The present search report has been drawn up for all claims</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 33%;">Place of search  THE HAGUE</td> <td style="width: 33%;">Date of completion of the search  26 April 2002</td> <td style="width: 33%;">Examiner  Van der Poel, W</td> </tr> <tr> <td colspan="3">           CATEGORY OF CITED DOCUMENTS            X : particularly relevant if taken alone            Y : particularly relevant if combined with another document of the same category            A : technological background            O : non-written disclosure            P : intermediate document         </td> </tr> <tr> <td colspan="3">           T : theory or principle underlying the invention            E : earlier patent document, but published on, or after the filing date            D : document cited in the application            L : document cited for other reasons            &amp; : member of the same patent family, corresponding document         </td> </tr> </table>				Place of search  THE HAGUE	Date of completion of the search  26 April 2002	Examiner  Van der Poel, W	CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document			T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document		
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Application Number  
EP 02 00 0169

DOCUMENTS CONSIDERED TO BE RELEVANT			CLASSIFICATION OF THE APPLICATION (InLCl.7)
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	
X	<p>DATABASE WPI Section Ch, Week 198426 Derwent Publications Ltd., London, GB; Class E36, AN 1984-162882 XP002176039 &amp; SU 243 580 A (AS UKR GAS INST), 15 January 1984 (1984-01-15) * abstract *</p>	1,7	
			TECHNICAL FIELDS SEARCHED (InLCl.7)
<p>The present search report has been drawn up for all claims</p>			
Place of search	Date of completion of the search	Examiner	
THE HAGUE	26 April 2002	Van der Poel, W	
CATEGORY OF CITED DOCUMENTS			
<p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p>			
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EP 02 00 0169

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